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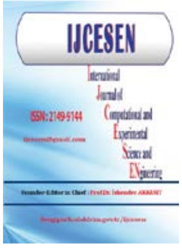

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Research Article

Need of Traceable Force Measurements in Steel Industry in Meganewton Level Forces[#]

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Abstract: In mechanical engineering, aerospace industry, energy industry, builting industry, safety engineering and testing, forces with nominal values in excess of 15 MN are measured. When we come to steel industry, need of MN level force measurements reach up to 100 MN level forces. Especially in rolling, pressing and extrusion process in steel and iron industry uses the MN level forces which are used in process control and development of high quality products. For this reason, MN level force should be measured reliably and accurately in iron and steel industry for repeatable products. In order to get reliable and accurate measurement results from the force measuring devices, they need calibrations traceable to international force standards. In this study, needs on MN level force measurements in iron and steel industry and subjects on traceable force measurements will be discussed.

1. Introduction

In recent years, It is understood that the process control is much more effective, efficient and productive during the manufacturing process of the products instead of one by one control of the finished products. Beside this, measurement systems are essential to perform process control in production line for continuous control to keep the production rate in high levels and to decrease the number of unexpected or waste products. For these reasons, force measurement is one of the most important parameter in process control, especially in steel industry. Competition in industry oblige the producers applying test on their products to present more reliable and high-quality products to the society to increase the market share and reliability. In these tests, different type material testing machines (MTM) and their equipments are used to check technical specifications of the materials and finished products. These MTMs measure the applied forces on the materials and products during tests. In order to get reliable measurement results from the MTMs and other test equipments, traceable force measurements are very important to get accurate and reliable results for all applications. Traceable measurements mean applying calibration of the measurement/test devices using well known reference standard to determine measurement uncertainty of them [1-4].

Nowadays, the force measurements are needed in many field of industry. Especially accurate force measurements are required in many applications. These include the determination of the strength of materials, quality control during production, weighing, and consumer safety. For example, force measurement systems are used to determine when a missile has developed sufficient thrust to be released for take off and in auto safety tests. In the aircraft industry, force measurements are required to test the structural integrity of aircraft components

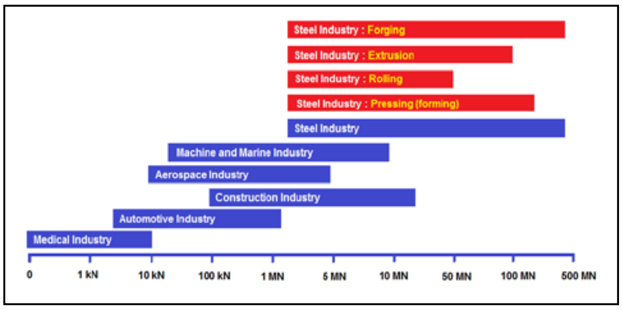

Figure 1. *Need of force measurement in different industries*

and structures. They are used to test the structural integrity of the wings, fuselage, and fasteners used in aircraft production. Similarly, accurate force measurements are required to determine the weight of vehicles, tanks, bins, ladles and hoppers. Force sensors (load cells) are used in electronic balances to measure weight. Such balances include those used to weigh trucks on highways, freight cars on railroads, many weighing applications and the flow of materials in a production process [5-6].

In steel industry, forging, rolling, pressing and extrusion process need also accurate force measurements. Automated industrial processes such as rolling mills require accurate force measurement to control roll pressure on bar steel, plates, sheet metal, etc. for the production of required technical specifications and repeatable products manufactured in different times ordered by costumer. Need of force measurements in different industry are shown in Figure 1.

A measurement technology offering high accuracy is a prerequisite today in steel industry for modern rolling, pressing and extrusion process. The constant striving to achieve optimum process quality and the highest possible productivity is essential goal of modern production units.

A truly measured force is crucial in achieving correct setting of production systems for optimum force distribution, correct force application to the material is beneficial to save of energy of production systems and less waste products and time consuming and etc.

In order to be able to make reliable and accurate force measurements using force measuring devices (force proving instruments) such as force transducers, load cells, dynamometers, proving rings, the traceable calibration of them are necessary and very important for reliability of the measurement results. For the calibration of force proving instruments well known standard forces should be generated by the force standard (calibration) machines (FSMs).

MegaNewton (MN) level force measurements are needed in numerous fields of industry such as aerospace, machine, marine, railroad and all other industries need higher forces up to 30 MN [3]. Especially in metal industry, MN level force measurement reaching up to 100 MN (10.000 tons-force) are used to control the processes in rolling, extrusion and pressing operations to specify a quality standard and to improve the productivity. In this study, MN level force applications especially in metal industry and the importance of traceable force measurements on controlling the process will be explained.

2. Need of MN Level Force in Steel Industry

A branch of heavy machine builting and steel industry produces various metal products (ranging from machine parts to household items) by forging, rolling, pressing and extrusion. The processes are based on the deformability of the materials, that is, on their ability to change their shape without destruction under the influence of external forces. Conditions favourable for plastic deformation are selected according to the fundamental principles of the theory of metal working by pressure. The value of forging and stamping methods is that the shape of the stock changes as a result of redistribution of metal rather than removal of excess metal, as in machining, which makes possible a sharp reduction in waste and a simultane ous increase in the strength of the material [7-8].

Therefore, metal working by pressure is used for the manufacture of very critical machine parts: 80-90 percent of the parts in aircraft and up to 85 % of the parts in automobiles (in terms of total weight) are made by pressing. Forging and pressing machines are more efficient than metal cutting machines; for example, the capacity of cold-heading machines is 5-6 times greater than that of automatic turning lath es, and metal waste is reduced by a factor of 2-3. For each million tons of rolled metal processed, 250,000 tons of metal can be saved with the use of mechanical stamping. [7]

Forging Forces

Forging process in which the workpiece is shaped by compressive forces applied through various dies and tooling. It is used for products weighing up to 200 t ons. Hydraulic forging presses with forces of 2-200 Meganewtons (MN), or 200-20, 000 tf. Forging stock is formed directly by the upper face of a stamp or by very simple accessories and forging tools. Presses are used for forming, forging and stamping processes. Mechanical presses crank or eccentric shaft driven, or knuckle-joint for very high forces; stroke limited apply forces on 2.7-107 MN (300-14,000 tf) forces. Hydraulic Presses constant speeds, load limited, longer processing times, higher initial cost than mechanical presses but require less maintenance apply forces on 125 MN (14,000 tf) open die, 450 MN (50,000 tf) closed die. Friction screw presses–flywheel driven, energy limited (if dies do not completely close, cycle repeats) apply forces on 1.4-280 MN (160-31,500 tf) [7-8].

Pressing (Forming) Forces

In order to forming of the metallic plate and sheet material, pressing is essential tool for metal industry.Pressing is a method of producing products made from various types of profiles, sections, bars, and pipes in which the forging stock is placed in a spec ial container, from which it is extruded by a punch (press plunger) through the opening of a die that has the shape of the intended product. Application of known pressing forces during pressing process is very important for determination of optimum force and it causes high quality products with low energy consumption. At the same time causes long life moulding due to low friction forces with optimum force application. Pressing is done on hydraulic presses with forces up to 200 MN (20,000 tf) [7].

Rolling Forces

Metal rolling is one of the most important manufacturing processes in the modern world. The large majority of all metal products produced today are subject to metal rolling. Metal rolling is often the first step in creating raw metal forms. Metal rolling is plastically deformed by compressive forces between two constantly spinning rolls. This force act to reduce the thickness of the metal and affect its grain size. The ingot or continuous casting is hot rolled into a bloom or a slab; these are the basic structures for creation of a wide range of manufactured forms. At a rolling mill, blooms and slabs are further rolled down to the intermediate parts such as plate, sheet, strip, coil, billets, bars, and rods. Many of these products will be starting materials for subsequent manufacturing operations such as forging, sheet metal working, wire drawing, extrusion and manufacturing. Blooms are rolled directly into I beams H beams, channel beams and T sections for structural applications. Rails are rolled directly from blooms. Plates and sheets are rolled from slabs and are extremely important in the production of wide range of manufactured items. It is important to understand the significance of metal rolling in industry today [8]. Rolling is done on rolling machines with forces up to 60 MN (6,000 tf) [7].

Figure 2. *A wiev from forging press and proces*

Extrusion forces

is the process by which a block/billet of metal is reduced in cross section by forcing it to flow through a die orifice under high pressure (compression force).

In general, extrusion is used to produce cylindrical bars or hollow tubes or for the starting stock for drawn rod, cold extrusion or forged products. Most metals are hot extruded due to large amount of forces required in extrusion. Complex shape can be extruded from the more readily extrudable metals such as aluminium.

Figure 3. *185 MN forging press*

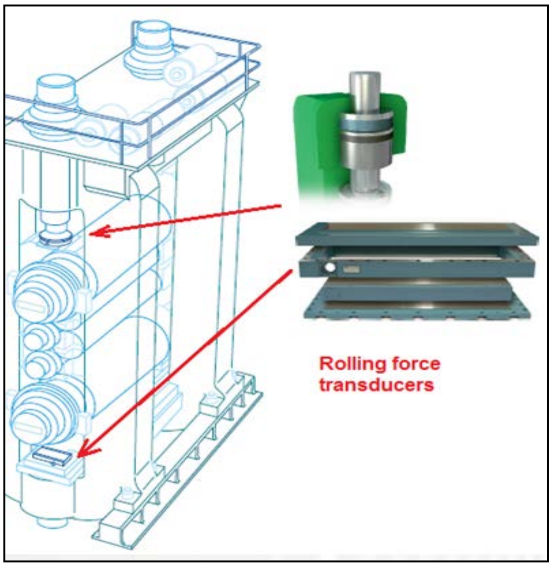

Figure 4. *ABB Rolling force transducers and their placement on the roll machine (1.6 MN to 60 MN)*

Figure 5. *Examples of extrusion presses and values*

Advantages of force measurement in metal processing

Generally compression forces are applied on the work piece by rolling, forging and pressing (forming) processes. Work piece subject to force by roller or press heads or forging hammers and its thickness reduced after every force application, so force is important for the control of the process. The advantages of force measurements in metal processing are given below:

- Increase in productivity
- Overload protection,
- Minimization of the problems which are causing from unknown forces,
- Obtaining the defined dimensions of the products, Improved product protection,
- Providing of quality standard and traceability,
- Providing of reliability in metal processing,
- Adjustment of the strain of sheet metals,
- Producing repeatable (similar technical specifications) products in different times,
- Low energy consumption due to optimum force application,
- Increasing in the usage life of processing machines such as roller, presses, extruders and hammers.
- Decreasing defects on the work pieces due to desired force application,
- Obtaining desired technical specifications from the work piece,
- Reduced energy consumption and waste.

Figure 6. *Rolling force measuring equipment*

The problems caused by uncontrolled force applications on the metal forming process

- Causing defects on the die, heads, hammers, bearings and spinning rolls of the metal forming machines due to overload force applications,

- Causing undesired product dimensions due to low or high force applications
- Causing wavy edge formations in metal sheets,
- Causing shortening of the life of machine due to overload force applications,
- Causing undesired mechanical properties in the work piece when suitable forces are not applied
- Causing cracks and microcracks on the products due to overload force application
- Metal forming processes cause some defects during process without force control.. Surface defects commonly occur due to impurities in the material, scale, rust or dirt. Internal defects caused by improper material distribution in the final products. Defects such as edge cracks, center cracks, and wavy edges are all common with metal forming processes of metal manufacturing. (8)

Force measurements in metal sheet pressing and hot or cold forging are important for high quality control, repeatability, non damaged production, low energy and for the use of time.

Figure 7. *Force applications in forging press*

Also force applications are necessary for forming metals such as in metal bending(edge bending-bending, bowingly elongation, spring back) deep drawing, stretch forming and ridge composing operations and in these operations force implementations play the leading role.

3. Traceable Force Measurements

Traceable calibration of the force proving instruments are necessary and very important for reliability of the measurements. For the calibration of them, well known standard forces should be

Figure 8. *Force in stretch forming of steel sheet*

generated by force standard (calibration) machines (FSMs). Different type force standard machines are used for calibration of force proving instruments in many national metrology institutes. Decision about type selection of force standard machines directly depends on the required accuracy of force generation and budget limitation of the institute or country. The most accurate forces can be generated by dead weights with direct application. But direct application of dead weights requires considerable builting space, when capacity of forces exceeds 100 kN. Dead weight force standard machines are quite expensive due to their high production cost. Cheaper solutions can be found for establishment of force scale in the country depending on the required accuracy and capacity. Some of these solutions are lever or hydraulic amplification of dead weights and built-up force standard machines, which amplifies the forces by hydraulic ram [1-2].

In the field of force, NMIs (National Metrology Institute) and calibration laboratories in industry use force standard machines with dead-weights, hydraulic amplification, lever amplification, a reference transducer or a built-up system (BUS) to cover the force range from low to high nominal values of 1 N up to 15 MN. Already the calibration of transducers on different calibration machines can show - depending on the transducer principle and the force introduction - significant deviations up to several per cent which are related to parasitic effects from the interaction of the force or moment vector with the calibration machine and from the different loading profile of the machines and the sensitivity of the transducer to these effects. This can result in significant contributions to uncertainty in applications. The user in industry, however, has no information thus far on how to take these effects into account. Currently, the calibration result considers only the calibration and not the use of the transducer in industrial applications [3]

Solution offered for the measurement of high forces

1. With single force transducer

   The single force transducer is manufactured by the producer but higher forces over the 15 MN it has faced with traceable calibrations due to lack of higher capacities force standard machines.

2. With many transducers combining built-up force transducers

   Built-up system is good solution to reach higher forces combining 3 or 9 or 27 pieces of single calibrated transducers. For this reason, the built-up systems are getting more and more popular as it is an effective method to increase the higher ranges. Each transducer are calibrated by force calibration/standard machine to get traceability and combined in triangle form to establish built-up system.

Figure 9. *Combining three 1 MN force transducers for 3 MN built-up transducers*

For example, 3 force transducers with a nominal force of 1 MN each, it can measure compression force with a nominal force of 3 MN. Three single 1 MN force transducers are combined between lower and upper plate in triangle shape in parallel shown in Figure 9. Electrically a junction box switches the output signals of the three transducers in parallel [5].

Measurement uncertainty of the built-up system, an expanded relative uncertainty value, W, for single force transducer can be calculated [10-11]

$$w_c = \sqrt{\sum_{i=1}^{8} w_i^{\,2}} \qquad (1)$$

w1 is the relative standard uncertainty associated with applied calibration force;

w2 is the rel. std. uncertainty associated with reproducibility of calibration results;

w3 is the rel. std. uncertainty associated with repeatability of calibration results;

w4 is the rel. std. uncertainty associated with resolution of indicator;

w5 is the rel. std. uncertainty associated with creep of instrument;

w6 is the rel. std. uncertainty associated with the drift in the zero output;

w7 is the rel. std. uncertainty associated with the temperature of the instrument;

w8 is the rel. std. uncertainty associated with interpolation.

In order to develop measurement uncertainty of built-up force transducer, relative standard uncertainty associated with long-term stability of force transducer winsta should be added to the equation (1) , then relative uncertainty of single built-up force transducer, wbu-ft [12-13] can be calculated as equ. (2)

$$w_{bu-ft} = \sqrt{w_c^2 + w_{insta}^2} \qquad (2)$$

Combination of each single built-up force transducer creates built-up system (BUS) with parallel connection shown in Fig.9. Relative uncertainty can be calculated as a summation of uncertainty of single built-up force transducer. Number of single force transducer (n) can be selected as 3 or 9 or 27 according to the targeted built-up force machine capacity. The relative uncertainty of built-up system, w_{BUS} can be calculated as equ. (3). The coefficients of this fit are then multiplied by the coverage factor k =2 relative uncertainty value, W_{BUS}, for any force (F) within the calibration range.

$$w_{BUS} = \sqrt{\sum_{i=1}^{n} w_{bu-ft}^{2}} \qquad (3)$$

Expanded standard uncertainty of the built-up system (U_{BUS}) is calculated as given in eq. (4)

$$W_{BUS} = k \times w_{BUS} \quad \text{and} \quad U_{BUS} = W \times F \qquad (4)$$

In order to calibrate high range force transducer over the force scale of NMI of the country a single force transducer is calibrated using built-up system as it shown in figure 10. As a result that high capacity force measurement needed by the verification of the machines used in metal industry such as extrusion, pressing, forming and forging machines can be performed by using built-up system for traceable force measurements.

Figure 10. *Calibration of 5 MN single force transducer using 9x540 kN built-up transducer [NPL]*

3. Conclusion

The force measurements are needed in many field of industry. Especially accurate force measurements are required in many applications. A measurement technology offering high accuracy is a prerequisite today in all industry including metal industry for modern rolling, pressing and extrusion process. In order to be able to make reliable and accurate force measurements using force measuring devices, traceable calibration of them are needed and very important for reliability of the measurements. For the calibration of them, well known standard forces should be generated by force standard (calibration) machines (FSMs). Traceable force measurement can be done using built-up system in MN level forces in steel industry with 5×10^{-4} to 5×10^{-3} measurement uncertainty [11]. This cause to increasing products quality, decreasing defects on products, increasing operating safety, decreasing products cost and obtaining similar products for subsequent orders it means producing repeatable products. Traceable force measurement in MN level in steel industry causes to increase product quality and competitiveness in steel market as well.

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